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Case Report

A physiological case study of a paralympic wheelchair tennis player: reflective practise

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Abstract
This study was designed to examine the physiological changes caused by long-term training in a world class female tennis player in preparation for a major championship. Additionally, we aim to describe the training interventions and determine a suitable cooling strategy that was to be used at the 2004 Paralympic Games. The athlete underwent regular physiological assessment during 2003–2004. Physiological measures involved body composition, submaximal and peak oxygen uptake and key variables associated with maximal sprinting. In addition, a suitable match-play cooling intervention and hydration strategy was also explored. Body composition improved over the course of the study. Aerobic capacity fell by 21%, yet the submaximal physiological variables such as lactate profile and pushing economy improved. The trade off of aerobic capacity was perhaps noticeably counter-balanced with the maintenance of the peak sprinting speed and improvement found in the fatigue profile across ten repeated sprints. The extensive training programme was responsible for these changes and these adaptations resulted in a more confident athlete, in peak physical condition leading into the Paralympic Games. It is difficult to appreciate the extent to which this work had an impact on tennis performance given the skill requirements of wheelchair tennis and this warrants future attention.

Key words: Wheelchair propulsion, aerobic capacity, longitudial study, training.

Introduction

Wheelchair tennis is now firmly established as one of the public's favourite Paralympic sports, having become a full medal sport at the 1992 Barcelona Paralympics. The sport also boasts a highly competitive, international tennis tour comprising over 100 tournaments worldwide, with prize money on offer. The court dimensions and rules of the game are identical to able-bodied tennis, except that the ball is allowed to bounce twice and this second bounce does not have to land within the court area. The game itself is characterised by short, intermittent sprints interspersed with sub-maximal pushing and regular rest periods. International tournaments take place over 2-7 days and are often played in hot and humid climates with players regularly required to play more than one match in a day (singles and doubles). Unpublished data collected from the GB team during the support period at an international tournament revealed matches may last 1-3 hours with typical average heart rates for a match ranging from 50-80% of maximum and peak heart rate values within 5% of maximum, depending on the quality of opponent. This data is supportive to earlier work which found that the average heart rate values during wheelchair tennis corresponded to 68% of maximum (Coutts, 1988).

This paper reports the results of a two year study of a World Class female wheelchair tennis player. At the time of this work, the athlete was preparing for the 2004 Athens Paralympics and underwent regular physiological assessments. These assessments involved measurements of body composition, peak oxygen uptake and key variables associated with maximal repetitive sprinting as reported in previous physiological applied work in the UK (Goosey-Tolfrey, 2005). On completion of each assessment day, a comprehensive picture of adaptations in the physiology of the player to training were obtained. The global aim of the physiological monitoring was to ensure that this player was in peak physical condition for this major event. In addition to the generic physiological support programmes that have been reported previously for Paralympic athletes (Goosey-Tolfrey, 2005), there were other significant physiological considerations that needed to be made. These were based upon the fact that high temperatures were expected for the 2004 Paralympics, which given the fact as individuals with a spinal cord injury (SCI) have impaired thermoregulatory function, may increase the risk of this athlete developing hyperthermia (Price, 2006). Consequently, additional support was proposed to look at possible cooling interventions for this player during tennis match play.

The purpose of this study was: (a) to provide the physiology of a World Class female wheelchair tennis player; (b) to determine the effectiveness of the player's training programme and to describe the interventions provided and (c) to investigate the effect of a cooling strategy that could be used at the 2004 Paralympic Games. Ultimately we hope to demonstrate the role of sport science support as a holistic yet scientific approach to understanding and practicing the principles of science during training and competition. This case study is an exemplar of how sports science support within disability sport is enhanced through the cooperation of the sports governing body and both the adherence and acceptance from athletes and coaches alike. Moreover, it attempts to provide a unique insight into the physiological adaptation to a major competition, which is considered to be a valuable contribution to the scientific knowledge (Schumacher et al., 2005), particularly within the field of disability sport.

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Methods

Participant

This study received Institutional ethics approval. Thereafter, the player underwent six physiological assessments over a 2-year period leading up to the Athens Paralympic Games. The player was 33 years of age at commencement of the study and had 8 years of wheelchair tennis playing experience and ten years of manual wheelchair experience. The individual was a paraplegic with an incomplete spinal cord lesion at the level of the 1^{st} lumbar vertebra (L1), resulting from a trauma incident and therefore competed in the Open division. Training details are difficult to summarise during the tennis competitive calendar, in general, the development of the training programme reflected the transition of moving into a Paralympic Year. Yet the tournaments remained the same but the focus shifted from the development of a sound 'aerobic base' to more on-court match fitness. The athlete involved in this case study has given express consent for their data to be presented in this format.

Exactly the same procedures and testing equipment were used for each test session, and the tests commenced at the same time of day (11-12 am). Moreover, the player was asked to refrain from vigorous exercise the day before testing and to arrive to the laboratory in a hydrated status, as to reduce diurnal and technical measurement errors (Jones, 1998). Irregularly of the menstrual cycle was reported, so it was difficult to always perform testing at the same phase of the athlete's menstrual cycle. The testing session was divided into three parts. The first part comprised of anthropometric and resting measurements, the second included submaximal wheelchair propulsion and measurements for determination of VO_2 peak, and the third a sprint performance test.

Anthropometric and resting measures

Body mass and skinfold measurements were used to monitor changes in body composition. Body mass was measured to the nearest 0.1 kg for the participant using a seated beam balance scale (Seca, Germany). Skinfolds were determined at the biceps, triceps, subscapular and supra-iliac using skinfold callipers (John Bull, St. Albans, England) (Durnin and Womersley, 1974). The sum of these four skinfold measurements was calculated rather than an estimated body fat percentage. Kocina (1997) highlights the fact that model-based equations yield invalid estimates of body composition in the SCI population due to alterations in the proportions of minerals, protein and water following SCI. Measurements were not taken from the lower limbs as it was felt this would not represent functional areas of the body.

Resting lung function using a Vitalograph spirometer was assessed in order to determine forced vital capacity (FVC), forced expiratory volume in 1 sec (FEV_1) and the FEV_1 /FVC ratio. It has been suggested that such measures can be diagnostic of viral infection and/or airway resistance (Szababdi, 1988). Furthermore, yet not particularly expected for this individual (incomplete, L1 lesion), some individuals with SCI demonstrate significantly lower values in such tests due to paralysis of the abdominal musculature, reduced pulmonary compliance and reduced diaphragmatic excursion (Gater, 2003). Understanding limitations to resting lung function is therefore important to understanding individual limitations to exercise performance in this population. Resting blood pressure was assessed prior to each testing session in order to screen for any abnormalities in blood pressure prior to testing (Figoni, 1997).

Instrumentation for performance measures

All performance tests were performed on a stationary roller wheelchair ergometer (Bromakin, Loughborough) please refer to Goosey-Tolfrey (2005) for specific details. Wheelchair ergometry was chosen over arm-crank ergometry as wheelchair propulsion is the actual mode of exercise in wheelchair tennis and players can be tested in their tennis-specific wheelchairs, allowing for a more meaningful physiological assessment (Davis, 1993; Glaser et al., 1980). In line with previous research, the player and tennis wheelchair was considered as one integrated unit, so any changes in chair configuration were not controlled for over time (Goosey-Tolfrey, 2005). As a result, changes in physiological performance data are to be attributed to the combined effects of training and changes in chair configuration. However, during each visit rear wheel tyre pressure was standardised to 758 KPa (7.58 bar).

Lactate profile

The protocol consisted of five to seven submaximal exercise stages of three minutes duration. Propulsion speeds were in the range of 1.0 – 2.2 $m \cdot s^{-1}$, and propulsion speed was increased by 0.2 m/s between stages. During the last minute of each stage, expired air was collected and analyzed using the Douglas bag technique. Heart rate (HR) was monitored continuously using radio telemetry (PE4000 Polar Sport Tester, Kempele, Finland). A small capillary blood sample was obtained from the earlobe at the start of the test and during a 1-min break between stages for determination of blood lactate concentration using a YSI 1500 Sport (Yellow Springs, USA). Rating of perceived exertion (RPE) (Borg, 1970) was monitored throughout the test.

Peak aerobic capacity

Following a 10-min rest period (standardised on all testing occasions), VO_2 peak was determined. This involved the player completing a continuous WERG test with 0.5 $m \cdot s^{-1}$ increments every min until volitional exhaustion. The starting power output was based on previous test results and was chosen to ensure that volitional exhaustion occurred within an 8-14 min period. Heart rate (HR) was monitored continuously using radio telemetry (PE4000 Polar Sport Tester, Kempele, Finland). Expired air samples were collected and analyzed using the Douglas bag technique over the last two consecutive stages of the test. On completion of the test, three minutes post, a small capillary blood sample was obtained from the earlobe, and analysed for blood lactate concentration using a YSI 1500 Sport (Yellow Springs, USA) and the final RPE was recorded.

The concentration of oxygen and carbon dioxide in the expired air samples was determined using a paramagnetic oxygen analyzer (Series 1400, Servomex Ltd., Sussex, UK) and an infrared carbon dioxide analyzer (Series 1400, Servomex Ltd., Sussex, UK). Expired air volumes were measured using a dry gas meter (Harvard Apparatus, Kent, UK) and corrected to standard temperature and pressure (dry). Oxygen uptake (VO_2), carbon dioxide output (VCO_2), expired minute ventilation (V_E), and respiratory exchange ratio (RER) were calculated for each Douglas bag. The analyzers were calibrated with gases of known concentration before each test and the linearity of the gas meter was checked using a three-litre calibration syringe. The criteria for a valid VO_2 peak was a peak RER value ≥ 1.10, and a peak HR ≥ 95% of age-predicted maximum (200 beats·min^{-1} minus chronological age; Lockette and Keyes, 1994). All testing sessions satisfied these criteria.

Anaerobic capacity

After a minimum of one hour recovery, the participant performed the final part of the test session. The anaerobic performance test involved the participant to propel their wheelchair on the WERG as fast as they could for a period of 10s, repeated every 30-s for 10 trials. The test was conducted from a 1.0 m.s^{-1} rolling start, and the initiation of the test was on a 3, 2, 1 countdown, and this countdown was repeated between sprints. A flywheel photo-optic sensor linked to the roller and interfaced to a PC computer recorded the velocity of the roller, at 100 Hz and calculated the power output at 1-sec intervals. The highest speed (m/s), during the sprint was recorded. It was also possible to assess anaerobic power and endurance by recording the highest speed achieved and assess the magnitude of the drop in speed across the ten sprints known as the fatigue index expressed as a percentage. This test was considered to be a performance test by the coach that was realistic to propulsion on the tennis court, therefore external resistance was not increased to limit the peak velocity attained. Pilot work at our laboratory for both the test protocols and equipment described above suggests a high level of reliability. For example, we have observed that peak speed (m/s) when measured on 5 separate days in an individual displayed an average range of 0.3 and a coefficient of variation of ± 0.04%.

Thermoregulation and cooling interventions

High temperatures were expected for the 2004 Paralympics and this was identified as a factor that could significantly impair performance. Therefore, support was provided to determine the physiological and performance effects of a practical cooling strategy that could be implemented during competition. Following additional Institutional ethics approval, the participant provided written, informed consent and performed two identical 60 min intermittent sprint protocols, on the wheelchair ergometer in an environmental chamber (30.4 ± 0.6 °C, 54.0 ± 3.8 % relative humidity). The participant underwent 30 min pre-cooling, using a cooling vest (Arctic Heat, Australia) prior to each trial. The intervention trial (INT) involved head and neck cooling during exercise using cooling hats (Blu Bandoo, USA) and neck bands (Frio Cooling Products, UK), while the control trial (CON) employed pre-cooling only. The sprint protocol consisted of five 10-min blocks of intermittent pushing with 2 min passive recovery in between. Each 10 min block was comprised of 2 min repetitions beginning with 10 s passive rest proceeded by a 5 s maximal sprint and followed by 105 s of moderate pushing (50% peak speed; PS). The highest speed achieved during each of the 5 s sprints was taken as PS during each test. Aural temperature and mean skin temperature were measured using a Grant Squirrel Meter (series 1250) and together thermal sensation (TS) were recorded every 2 min. Aural temperature (T_{au}) was employed in this study as rectal temperature is considered by some to be an inappropriate measure of core temperature in paraplegics during exercise (Price, 2006). Also recent work reported by Goosey-Tolfrey (2008b) has suggested that the exercise mediated increase in body temperature can be adequately recorded with this method in paraplegics.

Drinking bottles containing water which were taken inside the heat chamber during the exercise period were weighed at the beginning of each exercise session using a Top pan balance (Oertling 21TD, L Oertling Ltd, London, UK). During the rest periods, participants were free to take on fluids *ad libitum* and the amount consumed was recorded as the fluid intake. Changes in body mass and the volume of water consumed in each condition were used to calculate sweat loss.

Results

The body composition results of this athlete over the 2-year period are shown in Figure 1. Over the period of the study, the athlete's body mass decreased by 2.9 kg and the total skinfold values reduced by 46%. The average FEV_1 expressed as a percentage of FVC for this athlete over the testing period was 82%. Additionally the blood pressure for this athlete was within the normal range prior to each test.

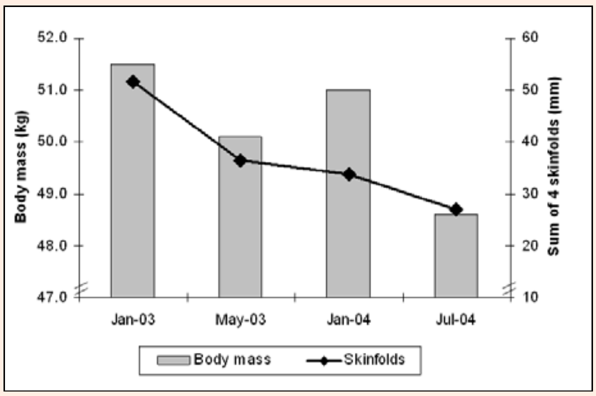

Figure 1. Changes in body mass and sum of 4 skinfolds from January 2003 – July 2004.

Of the physiological endurance related measures, following the athlete's visit in January 2004 the blood lactate profile demonstrated a slight upward shift compared to the previous visit (May 2003). However, upon returning to the lab in July 2004, the player's profile

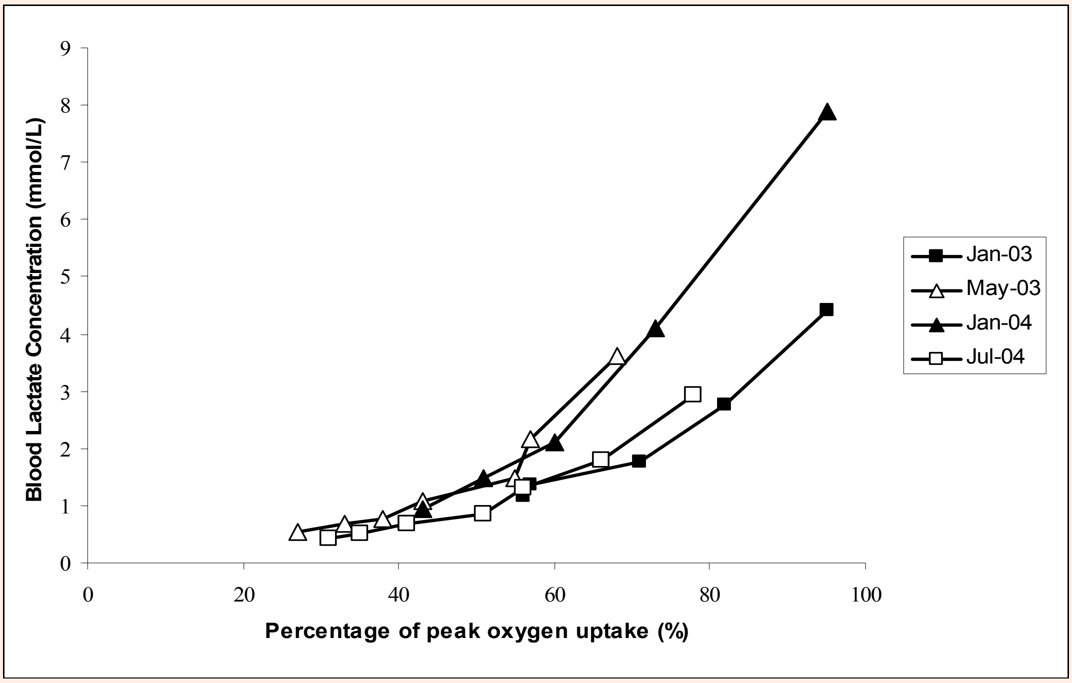

Figure 2. Effects of wheelchair tennis training on the blood lactate responses to incremental wheelchair propulsion exercise during.

showed the typical right and downward shift in the blood lactate response (Figure 2). Furthermore, there was a 23% reduction in VO_2 required to push at 1.6 m·s^{-1} (improved pushing economy) (Table 1 and Figure 3). The improved pushing economy offset the lack of improvement seen in the athlete's VO_2 peak (Table 1). From the sprint test perspective, over the course of the test period the peak speeds recorded on the wheelchair ergometer varied between 2.6 and 3.2 m·s^{-1} (Table 1). The fatigue index calculated across the ten sprints fell below 10% on the last two visits to the laboratory.

Figure 4 illustrates the effect of cooling garments on (a) thermal sensation and (b) mean peak speed during a simulated 1 hour exercise test in the heat. The results show that the thermal sensation was lower and the average peak speed was consistently higher for each set during the head/neck cooling condition compared to the control. This is particularly evident in the final two sets. The fact that the athlete felt cooler may have influenced the drinking strategy as the water consumed was found to be greater when no cooling devices were worn (0.90 vs. 1.95 litres respectively). However, there was no effect on the sweat rate which was around 1.1 - 1.3 litres for both conditions. Figure 5 shows the heart rate response across the 1-hour exercise in the heat and the effects of localised head and neck cooling. Delta (Δ) T_{au} values (temperature every two min minus baseline) over the two 60 min intermittent tests are shown in Figure 3. The Δ values were higher in CON compared with INT.

Discussion

Limited data are available on the physiological status of elite female Paralympic athletes and more importantly the longitudinal training effects. Although no published data on female wheelchair tennis players exists, it was felt that improvements in body composition could be made and the suggestion made to the athlete was to aim to reduce her body fat through healthy eating and increased volume of aerobic training. With the consent of the athlete, the data was referred to the team nutritionist in order to advise on dietary interventions. As the skinfold values declined over the period of support with a notable 2.9 kg reduction in body mass, it can be suggested that the multidisciplinary approach between physiology and nutrition

Table 1. Changes in key test parameters over the testing period.

Selected Physiological Data	Jan-03	May-03	Jan-04	Jul-04
Speed lactate test				
Pushing economy at 1.6 m·s^{-1} (L·min^{-1})	1.03	1.07	1.14	0.82
[Lactate] at 1.6 m·s^{-1} (mmol·l^{-1})	2.16	3.80	4.10	0.86
Peak test				
VO_2 peak (L·min^{-1})	2.06	1.98	1.47	1.63
VO_2 peak (ml·kg^{-1}·min^{-1})	28.0	39.5	28.8	33.4
HR peak (bt·min^{-1})	179	175	178	181
Sprint test				
Top speed (m·s^{-1})	2.9	3.2	2.6	3.2
Fatigue index (%)	17	14	8	9

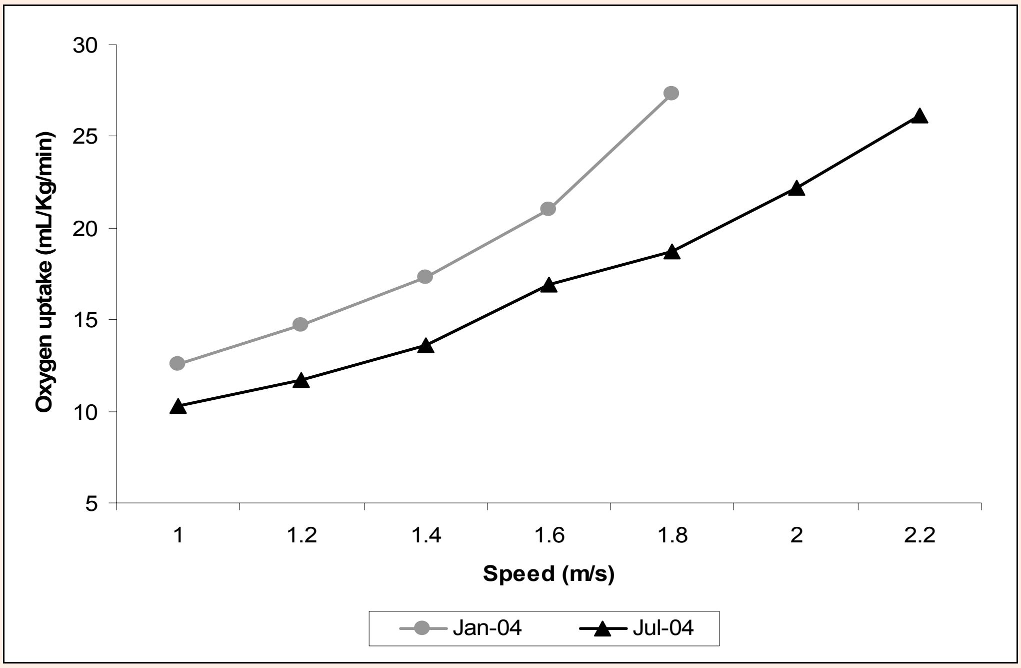

Figure 3. A comparison of the pushing economy profiles during the sub-maximal wheelchair propulsion tests conducted in January 2004 and July 2004.

was deemed to be effective. As the lung function and resting blood pressure for this athlete was within the normal range prior to each test no interventions or referrals were made.

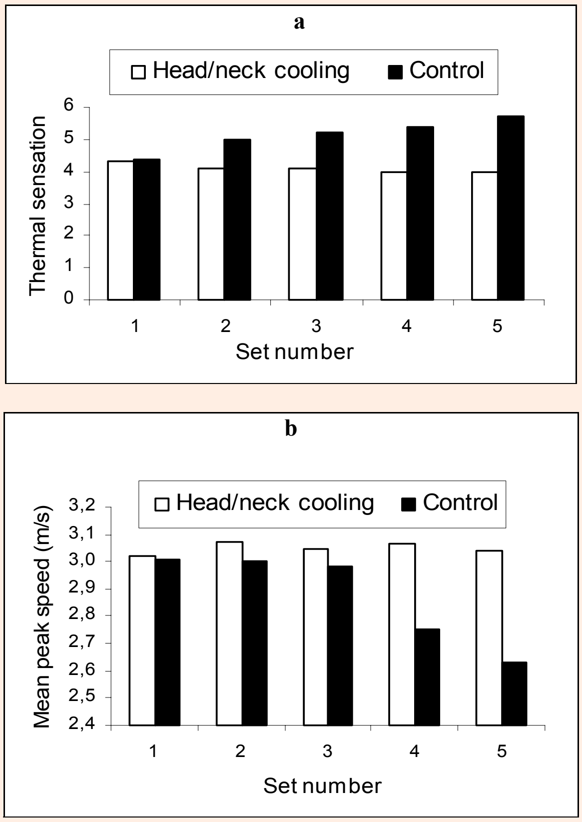

Figure 4. Impact of a cooling intervention during simulated wheelchair tennis in the heat on both (a) the thermal sensation and (b) the mean peak speeds achieved.

Given the demands of international wheelchair tennis, and the format of tournaments it can be argued that cardiorespiratory fitness is an important component for success at the international level. Furthermore it has been suggested that improvements in peak aerobic capacity can greatly enhance quality of life in persons with SCI in relation to activities of daily life, by increasing physical capacity (Janssen et al., 1994). As maximum aerobic capacity is considered by some to be the 'gold standard' measure of this component of fitness (Saltin and Astrand, 1967) it was decided to incorporate this into the test battery. Moreover, the ability to clear lactic acid formed in the muscle as a result of anaerobic metabolism is a fundamental component of 'functional' endurance (Weltman, 1995). As such, profiling the blood lactate and heart rate response to incremental exercise allows for the estimation of training zones and is a recommended protocol for exercise testing involving individuals with SCI (Figoni, 1997). As one of the aims of the support process was to prescribe recommendations for training it was decided that such a test would provide the information on which to base these recommendations. Furthermore, adaptations to training such as increased lactate clearance rates and/or decreased production of lactate acid (Weltman et al., 1992) and improved efficiency of wheelchair propulsion (Figoni, 1997) could be of potential benefit in terms of wheelchair tennis performance, and could be monitored on subsequent visits.

Lactate profile: The initial slight upward shift of the blood lactate concentration suggests a reduced endurance capacity (Weltman et al., 1992). This was likely due to a long lay-off during the Christmas period, coinciding with the end of the wheelchair tennis season. Upon returning to the laboratory in July 2004, the athlete's profile was back to a similar level as in Jan-03, with a lower production rate at the higher exercise intensities and a

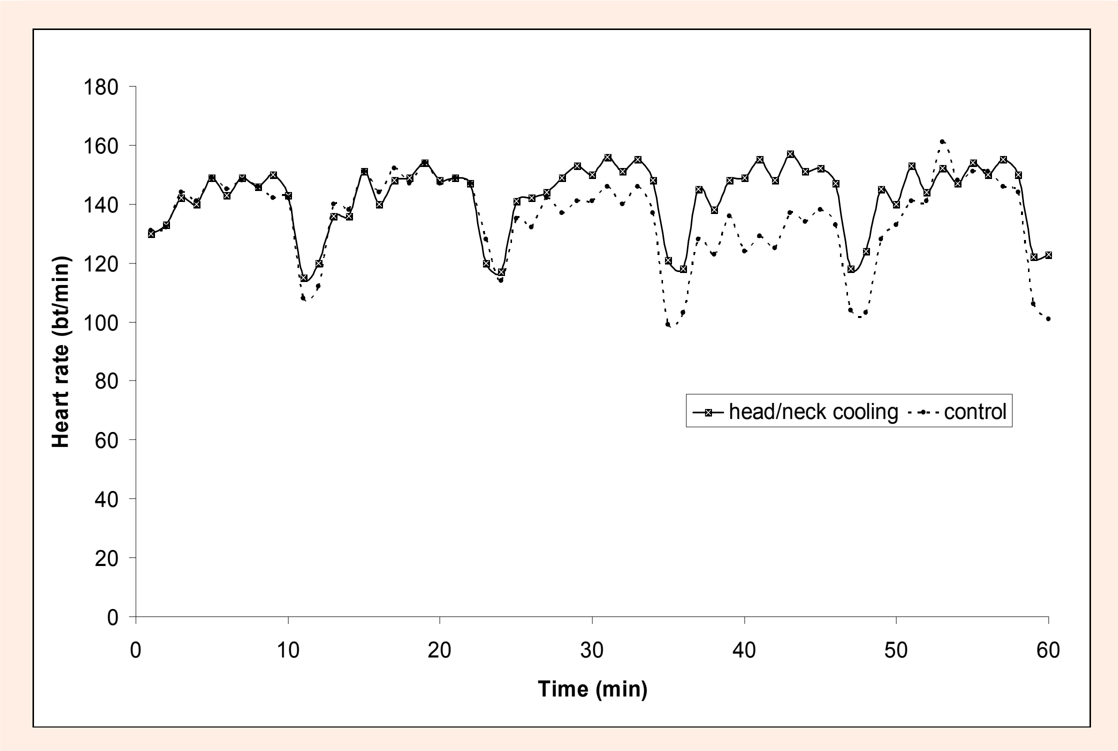

Figure 5. Impact of a cooling intervention during simulated wheelchair tennis in the heat on the heart rate response.

marked improvement in pushing economy as demonstrated by lower oxygen uptake values. The athlete was prescribed three sessions a week of steady pushing at a heart rate intensity of 130-140 beats·min^{-1} and it was suggested that these sessions should last 20-30 min. The athlete had access to a personal fitness coach and therefore, with the athlete's consent this individual was contacted and sent a copy of the report. This athlete also received specific support with this area during squad training camps.

Peak aerobic capacity: It has been suggested that absolute maximal oxygen uptake peaks at about 15 years of age in sedentary female, and reductions are seen thereafter (Krahenbuhl et al., 1985). Unfortunately there is no longitudinal data available in the SCI population to support this claim. The highest peak aerobic capacity of 39.5 ml/kg/min for this athlete compares well to previously reported female values of 33.7 ml·kg^{-1}·min^{-1} (Schmid et al., 1998). However, typically peak oxygen uptake tends to be expressed in relative terms due to the nature of the exercising musculature (Janssen and Hopman, 2005). Hence this is when fluctuations can be observed which may quite likely be due to the loss in body mass and maybe reduced muscle mass. Either way it was felt that this particular athlete's aerobic capacity could be developed further. Consequently, interval training was prescribed involving high intensity repetitions of 4 min duration.

Anaerobic capacity: The athlete's initial assessment in January (2003) revealed a 17% drop in peak speed across the ten sprints (Table 1). Previous unpublished work with elite wheelchair basketball players has demonstrated that athletes of a similar disability were capable of maintaining repetitive sprint efforts of approximately 10%. The aim was therefore to improve this athlete's anaerobic capacity. Therefore, a 'fan drill' was developed in order to address this issue and the athlete and coach were encouraged to incorporate this type of work into training sessions. Briefly this involved a series of repetitive sprints (25-30 sec duration) performed on court that were repeated up to four times. Fitness sessions at training camps with this athlete also focused on this area. As a result of this training, the fatigue index over the course of the study improved from 17% to 9%. However, the January-04 fatigue index of 8% may have also been due to the notable reduction in top speed on that test day.

Thermoregulation and cooling interventions: The disruption of autonomic nervous system function resulting from injury to the spinal cord means that individuals with SCI have impaired thermoregulatory control (Hagobian et al., 2004; Price, 2006). This problem arises as a result of interrupted afferent and efferent input to and from the hypothalamus concerning skin temperature, sweating and vasodilation below the level of injury (Chu and Burnham, 1995). This leads to reduced sweating capacity (Sawka et al., 1989) and limited control of blood flow distal to the lesion (Theisen et al., 2000) which can compromise sporting performance and put individuals with SCI at high risk of hyperthermia. Various cooling strategies have been shown to have a positive impact on performance as well as reduce thermal load and time to exhaustion in the heat (Marino, 2002). However few studies have investigated this in a SCI population and strategies that could be used during match-play situations. One such study demonstrated that the use of an ice vest as a pre-cooling strategy significantly reduced thermal strain in individuals with SCI (Webborn et al., 2005). Therefore it was decided adopt a similar strategy but to also incorporate head and neck cooling during exercise in order to attempt to prolong the effects of pre-cooling. The results of this intervention for this particular athlete were encouraging with cooling resulting in a lowered heart rate and mean peak sprinting speeds during a simulated wheelchair tennis protocol being maintained over a 1 hour duration compared to a control condition (Figure's 4 and Figure 5). The change in T_{au} from baseline indicated a trend whereby CON was consistently higher than INT after the first 18-min of exercise. The combined head and neck cooling strategy employed during the INT condition helped to slow the rise in T_{au} compared to CON towards the latter stages of the exercise. Moreover, these results suggested that the neck-band and cap strongly influenced how hot the athlete was feeling and appeared to have an impact on the amount of fluids drunk. Consequently, a fluid replacement strategy was put in place and a similar cooling strategy was successfully employed at the Paralympic Games. For more information on this topic area we direct the reader to Goosey-Tolfrey et al. (2008a).

The results from this case study clearly demonstrate that significant adaptations to training occurred during the two year support period and in many cases these adaptations were at their peak for this particular athlete, leading into the 2004 Paralympic Games. Furthermore, the cooling strategy and hydration strategy that was developed appeared to have a significant impact on this athlete's performance. Although the athlete did not medal at the Games, they achieved the goal of reaching the quarter final stages of the singles competition, finally losing to the World No.3 and eventual bronze medallist. In doing so, the player recorded a victory over an opponent ranked within the Top 5 in the world and soon became the new British No.1. Her world singles ranking also improved from outside the top 30 in January 2002 to 12 in 2004. Additionally, the coaching staff were extremely satisfied with the impact of the support provision. Given that skill is arguably the most important factor to success in international wheelchair tennis, it is difficult to appreciate the extent to which this work had an impact on tennis performance. However as the athlete was in peak physical condition (according to the tests that were conducted), and subjectively one of the best conditioned players in the world, fitness could not be used as an excuse in the event of poor performance.

Conclusion

Reflecting back on the 2 years spent working with wheelchair tennis we think that the introduction of sports science support to this sport had a profound and over-all positive impact on the sport. The outcomes of this work resulted in: (a) A greater awareness of the importance of physical preparation to performance; (b) Improved understanding of physiology including: training techniques, recovery, periodisation, nutrition and heat related issues e.g. cooling and hydration; (c) Increased levels of motivation as a result of being able to see improvements in aspects of physical fitness and (d) A more focused and targeted approach to training. However, there are some areas that could be improved, particularly relating to testing protocols and therefore suggested a move towards field-based testing. This would allow for the assessment of tennis-specific movements incorporating acceleration and agility, thus offering more useful and meaningful information to players and coaches.

Acknowledgments

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Key points

- Physiological adaptations were apparent over the two-year training period.
- The training emphasis resulted in a reduction in aerobic capacity, yet an improvement in repetitive sprint performance was seen leading into the Major competition.
- An effective cooling technique was identified that could be used during wheelchair tennis performance.
- The athlete and coaches were complimentary to the physiological support provided, which resulted in a more confident athlete at the Paralympic Games.

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